

# SEGREGATION OF SOFT WHITE WHEAT BY DENSITY FOR IMPROVED QUALITY

M. C. Siemens, D. F. Jones

**ABSTRACT.** *Development of a cost-effective way to segregate soft white wheat (*Triticum aestivum* L.) by quality would add value to a product that is currently marketed as a low-value commodity. Segregating grain by kernel density for improved quality is a technique that holds promise, but further research is needed. To address this, a study was initiated to determine the relationship of kernel density and soft white wheat quality in terms of test weight, protein content, milling performance, and end-use characteristics. The study was conducted in northeastern Oregon using Stephens soft white winter wheat samples collected from fields representing three different cropping systems over two crop years. Non-separated samples, samples that had been passed over a gravity table once and separated into four density fractions, and samples that had been passed over a gravity table twice and segregated into seven density fractions were analyzed for kernel density and quality characteristics. Correlations between quality characteristics and kernel density ranged from poor to high ( $r^2 = 0.00$  to  $0.82$ ) for non-segregated samples, but improved as the sample became more homogenous through segregation by density using a gravity table. For the samples that had been passed over a gravity table twice, wheat quality characteristics of test weight, protein content, milling score, mixograph absorption, and cookie diameter were highly correlated with kernel density ( $r^2 = 0.94$  to  $0.95$ ). Break flour yield was also highly correlated with kernel density ( $r^2 = 0.89$ ). When sets of data for samples that had been passed over the gravity table once and twice were analyzed collectively, correlations between quality characteristics and kernel density were similar, but slightly lower ( $r^2 = 0.88$  to  $0.94$ ). Quality scores calculated from these data and used to evaluate overall grain, milling, end-use, and overall wheat quality were also highly correlated with kernel density ( $r^2 = 0.91$  to  $0.96$ ). It was concluded that for homogeneous samples of one variety of soft white wheat, kernel density is an excellent indicator of wheat quality. Additional research is needed to determine if this result extends across multiple cultivars of wheat and additional crop years. Analysis of grain segregated into four density fractions showed that there were significant differences in wheat quality between the lowest density fraction, the highest density fraction, and the non-separated sample. These results further indicate that density segregation is effective for separating wheat by quality and were the impetus for the proposal of a new wheat classification system that uses overall wheat quality as the basis for determining grade. Such a system would provide a marketing advantage since wheat grade would better reflect grain value.*

**Keywords.** *Baking, Density, Flour, Kernel, Milling, Protein, Quality, Segregation, Test weight, Wheat.*

The privatization of world wheat (*Triticum aestivum* L.) markets over the last 15 years has brought a much sharper focus on quality and value (Oades, 2002). In the Pacific Northwest (PNW), where 85% or more of the soft white wheat grown in the region is exported, meeting customers' increasingly stringent quality requirements is critical for the industry to remain viable. Grain protein content, protein quality, and kernel texture are quality characteristics that affect nearly all milling and baking qualities of wheat (Gaines, 1991; Huebner et al., 1999). In the PNW, grain protein content and quality can vary

significantly across the region or even within a given field. Fietz et al. (1994) found that grain protein varied by as much as 36% from farm to farm in the Palouse region of Washington State and by as much as 51% among landscape positions within a given farm. Zwer et al. (1991, 1992) also found that PNW soft white wheat protein content can be highly variable, ranging from less than 7% to greater than 14% depending on cultivar and site location.

Development of a cost-effective way to segregate high from low quality wheat would increase grain quality consistency and potentially add value to crop that is currently marketed as a low-value, bulk commodity. Although various segregation approaches have been suggested (Baker et al., 1999; Arizmendi and Herrman, 2003; Maertens et al., 2004; Long et al., 2008), perhaps the system with the greatest potential for segregating wheat by quality is separation by kernel density. Low-density, pinched, shriveled kernels have a lower endosperm to bran and germ ratio as compared to high-density, sound kernels. This results in significantly poorer flour yield, flour quality, and baking performance (Gaines et al., 1997). Pinched and shriveled kernels also have higher protein content, which is an undesirable trait for soft white wheat since it negatively affects the quality of end-use products (Miller and Pan, 1992; Wilkins et al., 1993). Wilkins

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Submitted for review in January 2008 as manuscript number FPE 7351; approved for publication by the Food & Process Engineering Institute Division of ASABE in April 2008.

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et al. (1993) explored separating wheat by protein content using a gravity table. They found that protein content of non-irrigated, inland PNW soft white wheat was highly linearly correlated with gravity table position, with coefficients of determination ( $r^2$ ) ranging from 0.88 to 0.96. For all wheat lots examined, the least dense fractions and the densest fractions had significantly different protein contents and varied by much as 5.5%. Tkachuk et al. (1990) also investigated the effect of gravity table separation of five Canadian western red spring (CWRS) wheat lots with varying market grades. For any given wheat lot, they found that the densest fraction had the best flour-milling potential, the strongest physical dough properties, and the best baking quality. Since the dense fractions of low-grade wheat had improved market grade as compared to the non-separated sample, they concluded that use of gravity tables had enormous commercial potential for increasing the market value of low-grade wheat. This conclusion was confirmed by Tkachuk et al. (1991), who separated six feed-grade lots of hard red spring wheat with a gravity table and found that the densest fractions (42% to 81% by weight) qualified for an improved grade of No. 3 CWRS. This increased their market value by 20% to 40%. In the study, Tkachuk et al. (1991) also reported that the least dense fraction contained high concentrations of sprouted and shrunken and broken kernels. The remaining high-density fraction had higher test weight, improved milling performance and market grade.

Despite these promising results, use of gravity tables has seen limited commercial adoption for improving grain quality, especially for soft white wheat. One reason is that little is known about the effect of kernel density on soft white quality. Another is that gravity tables have relatively low processing rates of  $6.5 \text{ t h}^{-1}$ , which is inadequate for use at large elevators or terminal ports where thousands of tons per day are handled. Recently, equipment based on the fluidized bed principal has been developed for segregating wheat and other crops by density. These devices are capable of separating particles with density differences as small as 2% and can process up to  $136 \text{ t h}^{-1}$  at a cost of approximately  $\$2.93 \text{ ton}^{-1}$  (Camas International, Inc., Pocatello, Idaho, personal communication, 2 February 2002). Because commercially feasible technology is now available, research is needed to examine the potential of segregating wheat by density for improved quality and added value. To address this, a study was initiated to determine the relationship of grain density on soft white wheat quality in terms of test weight, protein content, milling performance, and end-use baking characteristics. A further objective was to determine if significant improvements in wheat quality and wheat quality consistency could be achieved through segregation of grain by density.

## METHODS

### FIELD SITE DESCRIPTION AND SAMPLE COLLECTION

The study was conducted using Stephens soft white winter wheat collected from three fields near Helix, Oregon, in 2004 and in 2005 that ranged in size from 5.8 to 10.7 ha. The three field sites selected each year represented commonly used cultural practices in the region. In 2004, these were no-till winter wheat following a season of chemical fallow (NT-CF), no-till winter wheat following chickpea (NT-AC), and

conventionally tilled winter wheat following a season of summer fallow (CT-SF). In 2005, the field sites chosen were again NT-CF, NT-AC, and conventionally tilled winter wheat following winter wheat (CT-AC). The “AC” designation is used here to indicate that a crop was raised annually, rather than biennially as with chemical or summer fallow systems. Soil at the sites is a well-drained Walla Walla silt loam (coarse-silty, mixed, mesic Typic Haploxerolls), and the average annual precipitation is approximately 365 mm. Grain samples (approx. 18 kg each) were manually collected during combine harvest from five landscape positions in each field. Landscape positions represented north and south hilltops, north and south facing sideslopes, and the drainage bottom. Samples were taken at three random locations within each landscape position in 2004 and at four random locations in 2005.

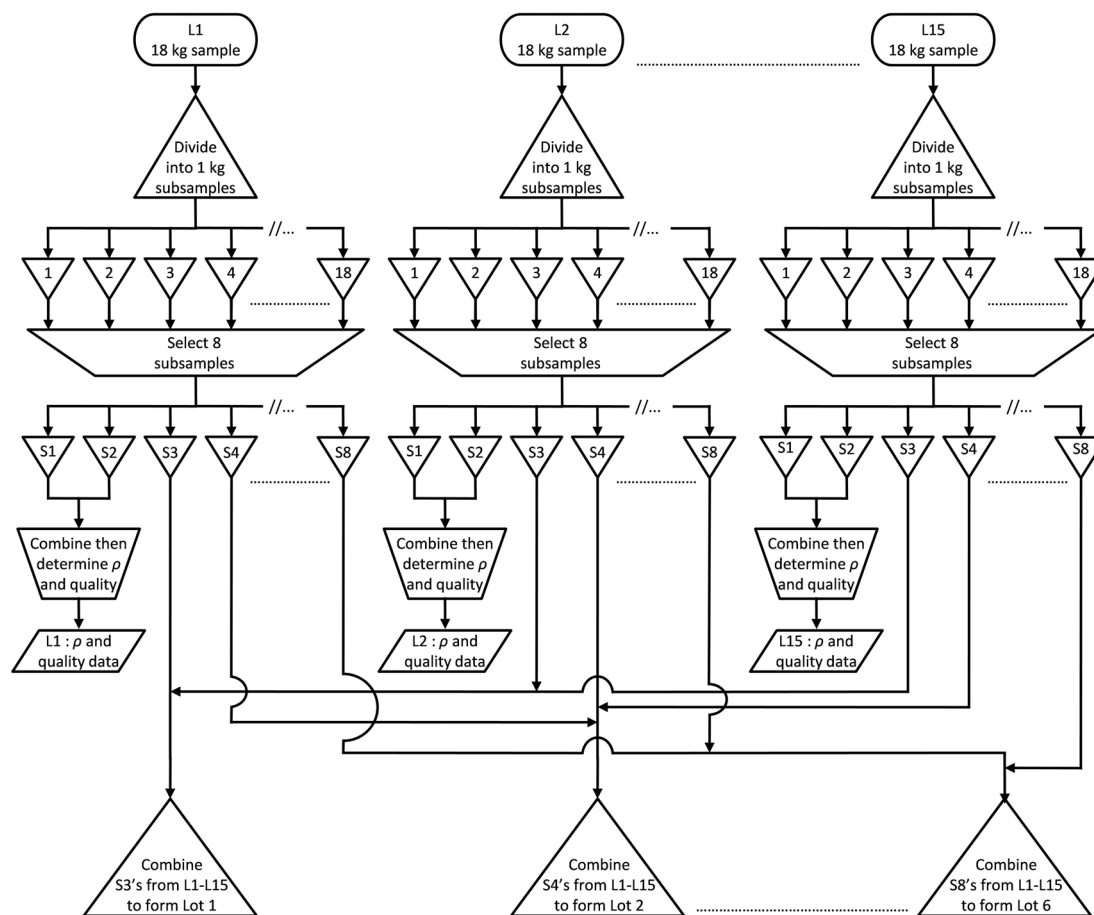
### SAMPLE PROCESSING, CROP YEAR 2004

Samples collected from each year were processed differently. For the samples collected in 2004, the 18 kg samples collected from the 15 sampling locations (L1 to L15) in each field were divided into 1 kg subsamples using a Boerner divider (fig. 1). Eight of these subsamples were randomly selected for each sampling location. Two of the subsamples were combined to form 2 kg samples that were representative of each sampling location.

The six remaining subsamples were used to form six lots of wheat that characterized the entire field. This was done by combining one subsample from each of the 15 sample locations, as shown in figure 1. Three of the wheat lots were separated into four density fractions using a gravity table (Sutton, Steele and Steele model V-135, Triple S Dynamics, Dallas, Tex.) and used as three replications. Positions of the centers of the four collection chambers were 51, 203, 356, and 508 mm as measured from the left lower deck edge where small light seeds exit. Gravity table adjustments include backslope and sideslope of the table deck, airflow, deck oscillation frequency, and material feed rate (Wilkins et al., 1993). Backslope and sideslope were set to  $3.5^\circ$  and  $4.5^\circ$ , respectively, and oscillation frequency was 6.7 Hz. Airflow and material flow rate were adjusted so that kernels would float and spread uniformly across the deck surface. The grain collected in each of the four chambers was randomly divided into 2 kg subsamples using a Boerner divider. Grain from the other three wheat lots was also randomly divided into 2 kg subsamples using a Boerner divider and used as replications for a non-separated sample. These subsamples and the 2 kg subsamples representative of each of the 15 sampling locations (L1 to L15) in each field were analyzed for kernel density and quality characteristics.

### KERNEL DENSITY AND WHEAT QUALITY DATA, CROP YEAR 2004

Kernel density was determined by first extracting about 60 g of grain from each subsample using a Boerner divider. From this 60 g, 1000 kernels were counted using a seed counter and then weighed to establish thousand kernel weight (TKW). A multipycnometer (Quantachrome Instruments, Boynton Beach, Fla.) operated with ultra-high purity nitrogen gas was used to measure thousand kernel volume. TKW was divided by its volume to obtain specific density ( $\text{kg m}^{-3}$ ). Test weight (bulk density), moisture content, dockage, and shrunken and broken kernel percentages were



**Figure 1.** Schematic of method used to process grain samples collected from fields near Helix, Oregon, in 2004. Diagram is for an individual field, L1 to L15 represent the 15 sampling locations, and  $\rho$  is grain density.

determined by a commercial grain inspection facility. Grain protein (12% mb) was determined using Leco combustion (Approved Method 46-30; AACC, 2000). Grain was tempered to about 14% moisture content and milled on a Buhler MLU202 mill (Buehler Ag, Uzwil, Switzerland) (Approved Methods 26-10A, 26-95, 26-31; AACC, 2000). Tempering moisture, milling time, break flour, and total flour yield were recorded, and flour ash content was determined (Approved Method 08-01; AACC, 2000). These data were used to determine overall milling performance by calculating a “milling score.” Milling scores are used by the USDA-ARS Western Wheat Quality Laboratory (WWQL) in Pullman, Washington, to evaluate wheat milling quality (USDA-ARS, 2008) and were calculated as follows:

*Milling score* =

$$100 - (80 - \text{Flour yield}) + 50 \times (\text{Flour ash} - 0.3) \\ + 0.48 \times (\text{Milling time} - 12.5) + 0.5 \times (65 - \text{Break flour}) \\ + 0.5 \times (16 - \text{Tempering moisture}) \quad (1)$$

where

*Milling score* is a dimensionless value used as an indicator of overall milling performance.

*Flour yield* is the percentage by weight of the total products recovered as straight-grade white flour.

*Flour ash* is percent ash content (Approved Method 08-01; AACC, 2000).

*Milling time* is the time required in minutes to mill a 2 kg sample and obtain normal separation of bran, shorts, and flour.

*Break flour* is the percentage by weight of the total products recovered as flour off the break rolls.

*Tempering moisture* is the moisture content (wet basis) of grain during tempering.

Baking quality characteristics evaluated were mixograph absorption (MABS) (Approved Method 54-40A; AACC, 2000) and cookie diameter (Approved Method 10-50D; AACC, 2000).

#### **SAMPLE PROCESSING AND KERNEL DENSITY, CROP YEAR 2005**

The method used for processing grain collected in 2005 is shown schematically in figure 2. First, a 2 kg subsample was randomly extracted from each 18 kg sample collected from each sampling location using a Boerner divider (fig. 2a). The remaining portion was then passed over the gravity table with the operating adjustments set to the same settings as used for the 2004 samples. Grain was separated into seven density fractions of about 2.3 kg each using collection chambers placed with their centers positioned 9, 95, 187, 279, 371, 464, and 556 mm from the left lower edge of the deck where light seeds exit. About 60 g of grain from each density fraction was extracted using a Boerner divider, and TKW and kernel density were determined as for the 2004 samples. The

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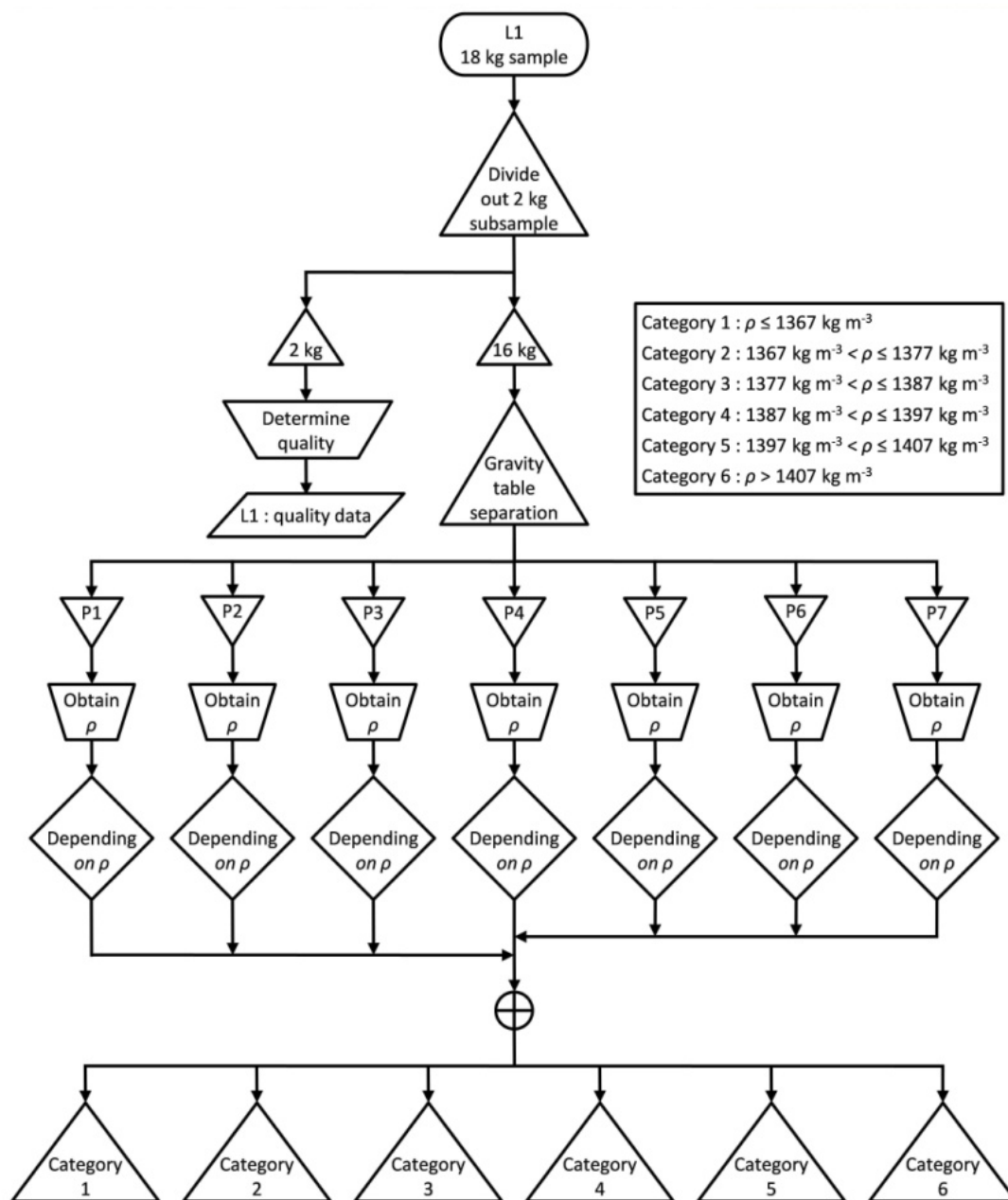


Figure 2. Schematic of methods used to process grain samples collected from fields near Helix, Oregon, in 2005 (a) for an individual sampling location (L1) and (b) for samples placed into one of six density categories by method (a). P1-P7 represent the seven gravity table discharge positions,  $\rho$  is grain density, and S1-S14 indicate the 14 samples tested for wheat quality characteristics (cont'd).

remaining portion of the 2.3 kg samples were placed into six categories depending on kernel density. The categories were defined by having densities of  $\leq 1367$ ,  $>1367$  to  $\leq 1377$ ,  $>1377$  to  $\leq 1387$ ,  $>1387$  to  $\leq 1397$ ,  $>1397$  to  $\leq 1407$ , and  $>1407 \text{ kg m}^{-3}$ . Maximum and minimum kernel density values for the lowest and highest density categories were chosen arbitrarily such that these two categories and the four equidistantly spaced intermediate density categories contained at least 14 samples.

For each density category, wheat lots were formed by combining eight randomly selected 2.3 kg samples from each category (fig. 2b). Each lot was passed over the gravity table

a second time to obtain fractions that were more uniform in kernel density. This also allowed fractions with a wider range in density to be obtained. Sixty gram subsamples of grain from each of the resulting 42 fractions (7 positions  $\times$  6 density categories) of wheat were removed using a Boerner divider, and kernel density was determined in the same manner as previously described. The samples were then arranged in order of ascending density, and every third sample (14 total) was selected for evaluation of its quality characteristics. Because kernel density was assumed to be normally distributed, this prescribed method of sample selection ensured that samples from the entire of range of kernel

b

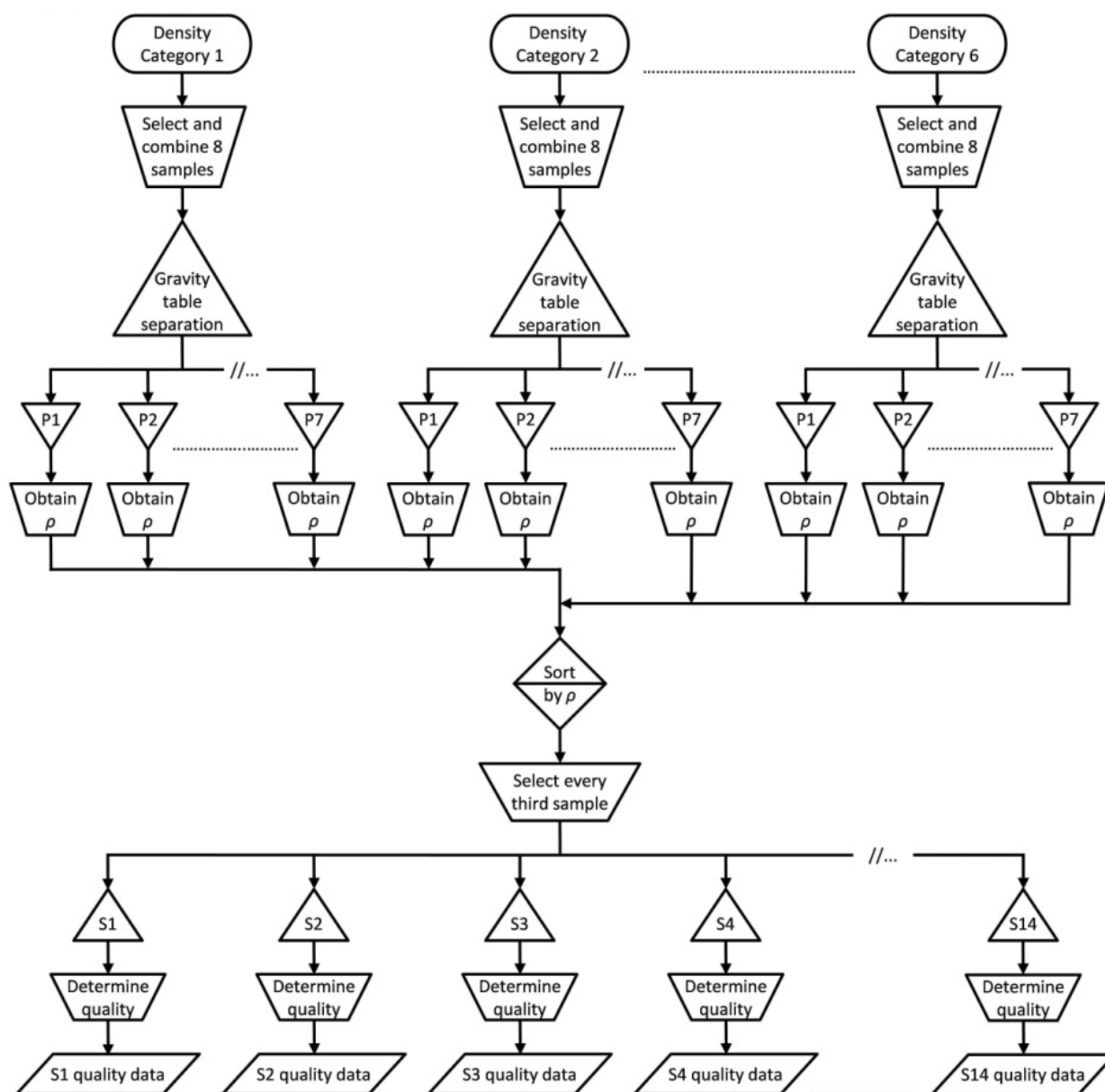


Figure 2 (cont'd). Schematic of methods used to process grain samples collected from fields near Helix, Oregon, in 2005 (a) for an individual sampling location (L1) and (b) for samples placed into one of six density categories by method (a). P1-P7 represent the seven gravity table discharge positions,  $\rho$  is grain density, and S1-S14 indicate the 14 samples tested for wheat quality characteristics.

densities were analyzed. This allowed for more comprehensive conclusions about the relationship of kernel density and soft white wheat quality to be made as compared to if samples were randomly selected.

#### WHEAT QUALITY DATA, CROP YEAR 2005

Test weight, protein content, MABS, and cookie diameter were all determined using the same methods as in 2004. Milling performance was determined in a manner similar to that used in 2004; however, grain was milled using the modified Quadrumat Sr. (C.W. Brabender Instruments, South Hackensack, N.J.) milling system (Jeffers and

Rubenthaler, 1979) rather than the Buhler mill since the machine was not available in 2005. Grain was tempered to about 13.5% moisture, and break flour yield, total flour yield and flour ash content were determined (Approved Method 08-01; AACC, 2000). A different milling score equation is used for the Quadrumat Jr. mill (USDA-ARS, 2008). This equation takes the following form with similar notations as equation 1:

Milling score =

$$[100 - (80 - \text{Flour yield}) + 50 \times (\text{Flour ash} - 0.3) + 0.5 \times (16 - \text{Tempering moisture})] \times 1.274 - 21.602 \quad (2)$$

## ANALYSIS AND WHEAT QUALITY SCORES

Quality characteristic data were compared to the mean and range in values of over 2100 samples of advanced line and control check varieties tested at the USDA-ARS WWQL in Pullman, Washington (Doug Engle, USDA-ARS WWQL, Pullman, Wash., unpublished data, 2005). Cookie diameter data were not available since the USDA-ARS WWQL uses a different baking procedure from the procedure used in this study. Although the data taken are commonly used measures of wheat quality, it is difficult to ascertain whether a particular lot of wheat has better overall quality than another lot since individual quality traits within a lot may vary significantly (Engle and Morris, 2002). To account for this, the USDA-ARS WWQL developed a scoring method that can be used to evaluate the overall quality of wheat lots (Engle and Morris, 2002). The technique takes into account grain, milling, and end-use quality. Grain, milling, and end-use scores are computed from a weighted equation of wheat quality measurements, and then these scores are used in a weighted formula to determine an overall wheat quality score. For soft white wheat, these equations take the following form:

$$\begin{aligned} \text{Grain quality score} &= \text{Test weight score} \times 0.2 \\ &+ \text{Protein score} \times 0.8 \end{aligned} \quad (3)$$

$$\begin{aligned} \text{Milling quality score} &= \text{Milling score} \times 0.6 \\ &+ \text{Break flour yield score} \times 0.4 \end{aligned} \quad (4)$$

$$\begin{aligned} \text{End-use score} &= \text{MABS score} \times 0.2 \\ &+ \text{Cookie diameter score} \times 0.8 \end{aligned} \quad (5)$$

$$\begin{aligned} \text{Overall grain quality score} &= \\ &\text{Grain quality score} \times 0.1 \\ &+ \text{Milling quality score} \times 0.4 \\ &+ \text{End product score} \times 0.5 \end{aligned} \quad (6)$$

Quality scores were computed using the following method. First, the mean and standard deviation were computed for each quality characteristic for the 2004 and 2005 data collectively. A high and low value for each quality characteristic was then calculated by adding or subtracting two standard deviations from the mean. Scores of 100 and 0 were assigned to the high and low values, respectively. A linear equation was derived between the high and low points and used to compute quality scores for the recorded data. Since lower values of protein and MABS are desirable, scores of 0 and 100 were assigned to the high and low values, respectively, for these quality characteristics. Unfortunately, cookie diameter data were not available for the 2004 data because of a sampling error during processing. As a

consequence, end-use scores and an overall quality score could not be computed. To account for this, a revised overall quality formula was used to estimate overall wheat quality for the 2004 data. It uses the same relative weighting of factors as equation 6, but was adjusted to account for the missing cookie diameter data with a scale factor so that the maximum value possible would also be 100. The equation takes the following form:

$$\begin{aligned} \text{Overall quality}_{\text{Adj.}} &= \\ &(\text{Grain quality score} \times 0.1 \\ &+ \text{Milling quality score} \times 0.4 \\ &+ \text{MABS score} \times 0.1) / 0.6 \end{aligned} \quad (7)$$

It should be stated that the USDA-ARS WWQL uses a different method for computing quality scores than the one used in this study. The USDA-ARS WWQL uses statistical analyses (t-tests) to compare varieties against a selected “check” variety (Engle and Morris, 2002). The t-score computed for each quality characteristic is used as the quality score. Because a check variety was not available, quality scores were computed using the method described.

The three replications of quality score data from the 2004 samples were averaged for each density fraction and for the non-separated samples. These data were used to determine the relationship of kernel density and wheat quality. They were also analyzed to determine if there were significant differences in quality between the fractionated samples and the non-separated samples using Fisher’s LSD ( $P = 0.10$ ) test (Schulman, 1992). Normal distribution plots were also made for the 2004 grain quality score data to help explain a proposed new wheat classification system that uses overall wheat quality and consistency as the basis for determining wheat grade. Probabilities for the normal distribution plots were calculated using the standard normal density function (Ang and Tang, 1975).

## RESULTS AND DISCUSSION

### FIELD SITE CROP YIELD AND GRAIN CHARACTERISTICS

Crop yield and overall grain characteristics for each of the three fields sampled in 2004 and 2005 are shown in table 1. Grain yield ranged from 2.4 to 6.1 t ha<sup>-1</sup> depending on cultural practices used and crop year, with crop yield being generally higher in 2004 due to greater precipitation during the growing season (Greenwalt, 2007). All fields produced grain that tested below the maximum allowable limit for damage, foreign material, defects, wheat of other classes, and shrunken and broken kernels (USDA-ARS, 2004). Consequently, test weight was the determining factor for

Table 1. Characteristics of field sites and soft white wheat samples collected near Helix, Oregon, in 2004 and 2005.

Year	Production System	Tillage	Grain Yield (t ha <sup>-1</sup> )	Wheat Grade (U.S.)	Test Weight (kg m <sup>-3</sup> )	Protein (%)
2004	Chemical fallow/winter wheat	No-till	6.1	2	771	12.3
	Chickpea/winter wheat	No-till	5.5	1	774	11.7
	Summer fallow/winter wheat	Conventional till	5.4	1	794	11.5
2005	Chemical fallow/winter wheat	No-till	5.4	2	747	12.4
	Chickpea/winter wheat	No-till	3.3	4	714	13.4
	Winter wheat/winter wheat	Conventional till	2.4	3	744	11.8

wheat grade. In 2004, two of the fields qualified for U.S. No. 1 wheat, while the third had a grade of U.S. No. 2. In 2005, grades ranged from U.S. No. 2 to U.S. No. 4. Since water stress increases protein content (Wilkins et al., 1993), marginal rainfall during 2005 was the likely cause of grain protein being generally higher in 2005 than in 2004 (table 1).

#### DISTRIBUTION AND DENSITY OF SEEDS EXITING A GRAVITY TABLE

Grain exiting the gravity tables was fairly evenly distributed between collection chambers, with roughly 25% of the grain falling into each of the four collection chambers in 2004 and about 14% of the grain deposited in each of the seven collection chambers in 2005 (table 2). For the 2005 samples passed over the gravity table once, average kernel density was  $1391 \text{ kg m}^{-3}$ . The distribution of grain in the six selected density range categories is shown in table 3. Almost all of the grain fractions (87% of total weight) had kernel densities that ranged in value from  $>1377$  to  $\leq 1407 \text{ kg m}^{-3}$ . About 4% of the grain by weight had densities  $>1407 \text{ kg m}^{-3}$ , while 3% of the grain by weight had densities  $\leq 1367 \text{ kg m}^{-3}$ . The low-density fractions contained mostly small, shriveled kernels and kernels that would be classified as shrunken and broken. These results suggest that the kernel density is normally distributed about the mean and that the majority of kernels were similar in size, weight, and aerodynamic properties.

#### CORRELATIONS BETWEEN WHEAT QUALITY CHARACTERISTICS AND KERNEL DENSITY

Quality characteristic data and associated kernel densities for the 2004 and 2005 data are shown in table 4. The data

show that passing samples over a gravity table a second time further segregated high-density kernels from low-density kernels. For example, when lot 3, which was comprised of samples ranging in density from  $>1377$  to  $\leq 1387 \text{ kg m}^{-3}$  was passed over the gravity table a second time, density values ranged from  $\geq 1363$  to  $\leq 1406 \text{ kg m}^{-3}$  for the seven discharge positions (all data not shown). The data contained in table 4 were used to generate linear correlations of kernel density and quality characteristics. Correlations were also made for data for the samples collected from the five landscape positions in each field for each crop year and for the 2005 samples that were passed over the gravity table once. Data for the samples collected from the five landscape positions in each field will henceforth be referred to as the "0-pass" samples to indicate that they were not passed over the gravity table. All quality characteristics were positively correlated with kernel density except protein and MABS, which were negatively correlated. Lower protein and MABS are desirable characteristics for soft white wheat. It should also be noted that correlations for MABS were calculated without using the three 2005 data points with densities  $\leq 1369 \text{ kg m}^{-3}$ . These points were significant outliers from the linear trend exhibited by the other 23 data points. Omitting them was considered permissible since less than 4% of the grain by weight had a density of  $\leq 1369 \text{ kg m}^{-3}$  and the  $r^2$  values calculated would therefore be representative for most grain. Additionally, interpreting MABS from mixograph charts is not an exact science and the standard methods used may not be accurate for the extremely poor-quality flour obtained from the shriveled grain contained in these samples.

For the 0-pass samples collected in 2004,  $r^2$  values for all quality characteristics and kernel density were less than 0.38 except for test weight where  $r^2 = 0.82$  (table 5). Break flour yield and milling score were not well correlated with kernel density ( $r^2 = 0.00$  and  $0.27$ , respectively). This result was surprising since test weight was highly correlated with kernel density and test weight is generally viewed as an indicator of milling quality (Bettge et al., 1989; Schuler et al., 1995). Although test weight was highly correlated with kernel density for the 2004 0-pass samples ( $r^2 = 0.82$ ), it was not correlated for the 2005 0-pass samples ( $r^2 = 0.00$ ). For the combined 2004 and 2005 0-pass data, correlations between test weight and kernel density were also low ( $r^2 = 0.26$ ). Although one would expect test weight to be highly correlated with kernel density, Schuler et al. (1995) also found poor correlation between soft red wheat test weight and kernel density in a two-year, multi-location study. Poor correlations can be explained by the fact that test weight is a bulk density measurement affected not only by kernel density but also by packing efficiency. Since packing efficiency is dependent on kernel size and shape, and kernel geometry is not necessarily correlated with kernel density, it follows that kernel density is also not always well correlated with test weight. Protein content was not well correlated with kernel density for the 0-pass 2004 samples ( $r^2 = 0.38$ ), the 2005 0-pass samples ( $r^2 = 0.01$ ), or the combined 2004 and 2005 0-pass data ( $r^2 = 0.12$ ). These results concur with those of Schuler et al. (1995), who also reported finding poor correlation between protein content and kernel density for non-segregated samples of soft red wheat ( $r^2 = 0.23$ ).

Relationships between kernel density and quality characteristics were much improved for samples that had

**Table 2. Distribution of seeds exiting a gravity table for soft white wheat samples collected near Helix, Oregon, in 2004 and 2005.**

2004		2005	
Discharge Position <sup>[a]</sup> (mm)	Weight Distribution (%)	Discharge Position <sup>[a]</sup> (mm)	Weight Distribution (%)
51	24	3	15
203	31	95	11
356	24	187	15
508	21	279	10
		371	16
		464	14
		556	19

<sup>[a]</sup> Position of center of collection chambers for grain discharged from gravity table measured from the left lower deck edge where small light seeds exit. In 2004 and 2005, four and seven chambers were used, respectively.

**Table 3. Distribution of seeds within six categorized density ranges for samples of soft white wheat separated into seven fractions using a gravity table. Wheat samples were collected near Helix, Oregon, in 2005.**

Category Number	Density Range ( $\text{kg m}^{-3}$ )	Weight Distribution (%)
1	$\rho^{[a]} \leq 1367$	3
2	$1367 < \rho \leq 1377$	6
3	$1377 < \rho \leq 1387$	21
4	$1387 < \rho \leq 1397$	38
5	$1397 < \rho \leq 1407$	28
6	$\rho > 1407$	4

<sup>[a]</sup>  $\rho$  = kernel density.

**Table 4. Kernel density and quality characteristics of soft white wheat exiting a gravity table at various discharge positions from samples collected near Helix, Oregon, in 2004 and 2005.**

Year	Production System <sup>[a]</sup>	Lot No. <sup>[b]</sup>	Discharge Position <sup>[c]</sup> (mm)	Kernel Density (kg m <sup>-3</sup> )	Test Weight (kg m <sup>-3</sup> )	Protein (%)	Break Flour (%)	Total Flour (%)	Flour Ash (%)	Milling Score	MABS <sup>[d]</sup> (%)	Cookie Diameter (mm)
2004	NT-CF	--	Non-sep	1408	771	12.3	48.4	69.6	0.45	81.7	56.6	--
		--	5.1	1398	736	12.8	47.5	68.3	0.45	80.1	57.7	--
		--	20.3	1410	776	12.2	49.2	70.7	0.45	83.5	56.5	--
		--	35.6	1415	784	11.9	49.2	70.8	0.43	84.5	56.6	--
		--	50.8	1417	789	11.7	50.2	72.1	0.45	85.0	56.0	--
	NT-AC	--	Non-sep	1413	774	11.7	48.6	69.9	0.38	86.5	56.6	--
		--	5.1	1404	741	12.4	46.9	67.3	0.42	80.8	57.3	--
		--	20.3	1413	783	11.5	48.4	69.5	0.38	86.2	55.8	--
		--	35.6	1420	789	11.4	47.9	68.9	0.40	84.1	55.6	--
		--	50.8	1420	793	11.4	50.1	72.0	0.40	87.9	55.9	--
	CT-SF	--	Non-sep	1414	794	11.5	47.0	67.6	0.36	84.7	56.6	--
		--	5.1	1412	774	11.3	48.3	69.4	0.39	85.3	56.8	--
		--	20.3	1416	797	11.4	48.0	68.9	0.39	84.9	56.2	--
		--	35.6	1419	801	11.6	47.7	68.5	0.36	85.8	56.6	--
		--	50.8	1420	804	11.6	47.9	68.8	0.37	85.8	56.9	--
2005	NT-AC	1	0.3	1346	555	18.6	31.0	47.5	0.53	47.9	62.3	69.8
	NT-AC	1	9.5	1363	608	18.8	33.9	52.3	0.47	58.2	63.3	70.7
	NT-AC	1	46.4	1369	663	17.7	38.9	58.1	0.43	68.2	63.6	72.7
	NT-AC	2	37.1	1376	680	16.3	40.7	60.4	0.41	72.0	63.9	73.7
	NT-CF, NT-AC, CT-AC	3	18.7	1379	632	16.8	36.7	54.9	0.43	64.1	64.6	73.2
	NT-CF, NT-AC, CT-AC	4	18.7	1392	753	14.1	43.8	65.3	0.39	79.7	62.6	75.1
	NT-CF, NT-AC, CT-AC	3	37.1	1395	736	13.1	45.5	67.5	0.39	82.4	61.4	75.4
	NT-CF, CT-AC	5	9.5	1402	740	12.6	40.9	62.4	0.35	78.6	59.1	75.3
	NT-CF, NT-AC, CT-AC	3	55.6	1406	756	13.2	45.2	67.5	0.39	82.5	59.7	76.0
	NT-CF, NT-AC	6	9.5	1408	789	11.6	48.0	72.0	0.38	88.6	57.6	77.4
	NT-CF, CT-AC	5	37.1	1411	794	12.1	48.0	71.0	0.37	88.5	56.6	78.2
	NT-CF, NT-AC	6	55.6	1415	808	11.7	48.7	72.2	0.35	91.1	55.7	76.6
	NT-CF, NT-AC	6	37.1	1416	803	11.5	48.4	72.0	0.36	90.4	55.2	77.1
	NT-CF, NT-AC	6	46.4	1418	803	11.4	47.8	72.1	0.35	90.9	55.1	78.7

[a] NT-CF = no-till winter wheat following a season of chemical fallow, NT-AC = no-till winter wheat following chickpeas, CT-SF = conventionally tilled winter wheat following a season of summer fallow, and CT-AC = conventionally tilled winter wheat following a season of winter wheat. In 2005, wheat samples from various production systems were combined to form a lot.

[b] Lot number corresponds to wheat density range category of whole sample prior to being passed over gravity table a second time. For lot numbers 1, 2, 3, 4, 5, and 6, these density ranges were  $\rho \leq 1367$ ,  $1367 < \rho \leq 1377$ ,  $1377 < \rho \leq 1387$ ,  $1387 < \rho \leq 1397$ ,  $1397 < \rho \leq 1407$ , and  $\rho > 1407$  kg m<sup>-3</sup>, respectively.

[c] Position of center of collection chambers for grain discharged from gravity table measured from the left lower deck edge where small light seeds exit. In 2004 and 2005, four and seven chambers were used, respectively; Non-sep = non-separated.

[d] Mixograph absorption.

**Table 5. Coefficients of determination ( $r^2$ ) for linear regressions of kernel density and soft white wheat quality characteristics for non-segregated grain and grain that had been segregated by a gravity table and collected near Helix, Oregon, in 2004 and 2005.**

Year	No. of Passes <sup>[a]</sup>	No. of Chamb. <sup>[b]</sup>	Test Wt. (r <sup>2</sup> )	Prot. (r <sup>2</sup> )	Break Flour (r <sup>2</sup> )	Mill Score (r <sup>2</sup> )	MABS <sup>[c]</sup> (r <sup>2</sup> )	Cookie Dia. (r <sup>2</sup> )	Test Wt. Score (r <sup>2</sup> )	Prot. Score (r <sup>2</sup> )	Grain Qual. Score (r <sup>2</sup> )	Break Flour Score (r <sup>2</sup> )	Mill Score (r <sup>2</sup> )	Mill Qual. Score (r <sup>2</sup> )	MABS Score <sup>[c]</sup> (r <sup>2</sup> )	Cookie Dia. Score (r <sup>2</sup> )	End-Use Score (r <sup>2</sup> )	Overall Qual. Score <sup>[d]</sup> (r <sup>2</sup> )	Overall Quality Score Adj. <sup>[e]</sup> (r <sup>2</sup> )
2004	0	--	0.82	0.38	0.00	0.27	0.34	--	0.82	0.38	0.48	0.00	0.27	0.23	0.34	--	--	--	0.44
2005	0	--	0.00	0.01	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
'04&'05	0	--	0.26	0.12	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
2004	1	4	0.91	0.73	0.18	0.73	0.55	--	0.91	0.75	0.86	0.18	0.74	0.60	0.56	--	--	--	0.73
2005	1	7	0.56	0.48	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
2005	2	7	0.95	0.94	0.89	0.95	0.95	0.94	0.95	0.94	0.95	0.89	0.94	0.93	0.95	0.94	0.95	0.96	--
'04&'05	1&2	4&7	0.94	0.94	0.89	0.89	0.88	--	0.94	0.94	0.95	0.89	0.89	0.91	0.88	--	--	--	0.94

[a] Number of times grain was passed over gravity table.

[b] Number of chambers used to collect grain exiting gravity table.

[c] Mixograph absorption. For 2005 and combined 2004 and 2005 ('04 & '05) data, coefficients of determination for MABS and MABS score are for data with kernel densities  $> 1369$  kg m<sup>-3</sup>.

[d] Overall grain quality score calculated from a weighted formula using grain quality score, milling quality score and end-use scores.

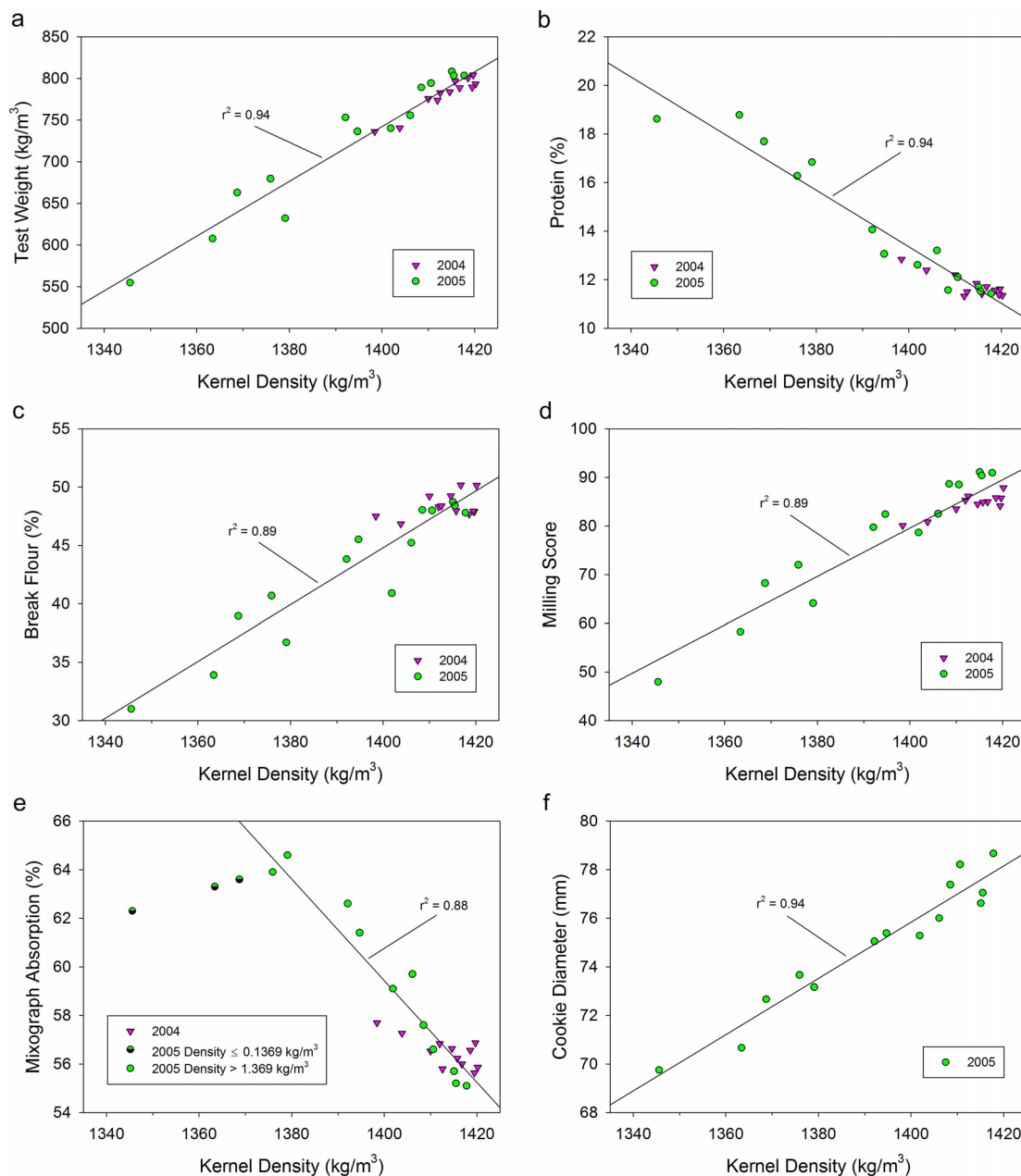
[e] Adjusted overall grain quality score calculated from a weighted formula using grain quality score, milling quality score and MABS scores. End-use scores were not available.



been passed over the gravity table. For the 2004 samples fractionated into four divisions,  $r^2$  values for test weight, protein, and milling score increased to 0.91, 0.73, and 0.73  $\text{kg m}^{-3}$ , respectively. For the 2005 samples passed over the gravity table once, test weight and protein were also reasonably well correlated with kernel density ( $r^2 = 0.56$  and 0.48, respectively). Passing the samples over the gravity table a second time improved correlations between kernel density and quality characteristics even further. Test weight, protein content, break flour yield, milling score, MABS, and cookie diameter were all highly correlated with kernel density ( $r^2 = 0.94$  to 0.95) (table 5). Break flour yield was also well correlated with density ( $r^2 = 0.89$ ). Correlations of the combined 2004 and 2005 data that had been passed over the

gravity table once and twice, respectively, were high ( $r^2 = 0.88$  to 0.95) for all quality characteristics. These results indicate that the high diversity in wheat quality of non-segregated samples can be effectively segregated by density using a gravity table.

Plots showing the relationship of wheat quality characteristics and kernel density for the 2004 and 2005 samples that had been passed over the gravity table are presented in figure 3. Other than the three data points with kernel density  $\leq 1369 \text{ kg m}^{-3}$  in the MABS plot (fig 3e), there were no significant outliers from the linear regression lines fit to the data. This fact is reflected in the high  $r^2$  values obtained for correlations of kernel density and quality data (fig. 3, table 5). The plots show that the high-density fractions



**Figure 3.** Effect of kernel density on soft white wheat quality characteristics for grain collected near Helix, Oregon, in 2004 and 2005 and passed over a gravity table. Samples collected in 2004 were passed over a gravity table once and separated into four density fractions. Samples collected in 2005 were passed over a gravity table twice and separated into seven density fractions. Linear regression line for the mixograph absorption data is based on data for kernel densities  $>1369 \text{ kg m}^{-3}$ .

of grain segregated from the stressed, low test weight, high-protein wheat collected in 2005 had similar quality to that of the unstressed, high test weight, low-protein grain collected in 2004. To help interpret the meaning of the graphical information presented, the mean, top 10 percentile, and bottom 10 percentile quality characteristic values of over 2100 samples of advanced lines and control check varieties tested at USDA-ARS WWQL are introduced. Mean values for test weight, protein content, break flour yield, milling score, and MABS were  $794 \text{ kg m}^{-3}$ , 10.6%, 47.3%, 84.1, and 54.4%, respectively, while top and bottom 10 percentile values were  $765$  and  $817 \text{ kg m}^{-3}$ , 8.2% and 12.9%, 42.4% and 52.2%, 78.2 and 89.7, and 51.6% and 57.5%, respectively (Doug Engle, USDA-ARS WWQL, Pullman, Wash., unpublished data, 2005). Again, cookie diameter data were not available since the USDA-ARS WWQL uses a different cookie baking test procedure from the one used in this study. Examination of these data showed that for the 2004 and 2005 data with kernel densities less than  $1390 \text{ kg m}^{-3}$  test weight, protein content, break flour yield, and milling score quality characteristics were poorer than 90% of the USDA-ARS WWQL samples. This is important in that grain with density of less than  $1390 \text{ kg m}^{-3}$  represented roughly 30% of the total grain by weight collected in 2005 (table 3). Removal of this low-quality wheat would significantly improve the overall quality of the 2005 wheat lot. High-density grain fractions with kernel densities near  $1420 \text{ kg m}^{-3}$  had test weight, break flour yield, and milling score values that were similar to those of the top 10% of the USDA-ARS WWQL samples. This is also an interesting result in that that about half of the cultivars tested by the USDA-ARS WWQL have quality characteristics that are superior to those of the variety Stephens used in this study (Engle and Morris, 2002). Further study is warranted on cultivars with high quality characteristics to determine the relationship between wheat quality and kernel density for these varieties and whether fractions of wheat with extraordinary quality characteristics could be obtained. All of the MABS values from this study were higher than the mean MABS value (54.4%) of the USDA-ARS WWQL data. An explanation for why the high-density fractions did not show improved performance for this quality characteristic could not be formulated.

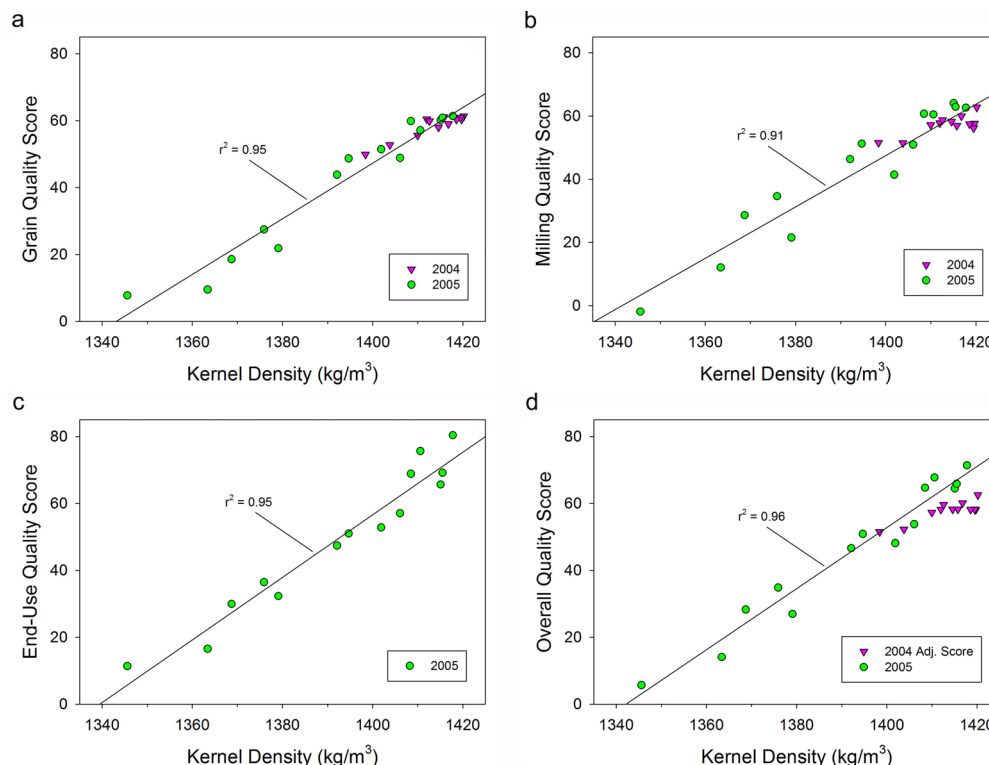
#### CORRELATIONS BETWEEN WHEAT QUALITY SCORES AND KERNEL DENSITY

Correlations of kernel density and computed quality scores for test weight, protein, break flour yield, milling score, MABS, and cookie diameter were nearly identical to those calculated for the respective raw, non-scaled values (table 5). This result validates the use of calculating quality scores from linear regression equations developed from means and standard deviations of the raw values, as described in the Methods section. As was the case for the raw data, correlations of kernel density and grain, milling, end-use, overall and adjusted overall quality scores were higher for segregated grain as compared to that of grain that had not been passed over the gravity table, and were highest for grain that was passed over the gravity table twice. Correlations of kernel density and calculated grain, milling quality, and adjusted overall quality scores for the 2004 0-pass grain were fair ( $r^2 = 0.48, 0.23, \text{ and } 0.44$ , respectively). After passing the grain over a gravity table,  $r^2$  values for these quality scores improved to  $0.86, 0.60, \text{ and } 0.73$ , respectively. For the 2005

samples passed over the gravity table twice,  $r^2$  ranged from  $0.93$  to  $0.95$  for all quality scores except for break flour yield score, where  $r^2$  was  $0.89$ . These results are reflected in the high correlation of overall quality score and kernel density ( $r^2 = 0.96$ ). Correlations for the combined 2004 and 2005 data were similar to but slightly lower than correlations for the 2005 only data. Correlation of kernel density and adjusted overall quality score for the combined 2004 and 2005 data was also high ( $r^2 = 0.94$ ). These results indicate that grain, milling, end-use, and overall quality of wheat is correlated with kernel density and becomes increasingly more correlated as the homogeneity of grain improves through segregation. Plots showing relationships of kernel density and grain, milling quality, and end-use quality scores are shown in figure 4. Regression lines fit to the data again show few outliers, which is reflected in the high  $r^2$  values obtained. Slopes for all quality scores were similar, suggesting that kernel density has about the same effect on scaled quality scores for all quality factors. An explanation for the high correlation between wheat quality and kernel density is again that low-density, shriveled kernels have a lower ratio of endosperm to bran and germ and higher protein content as compared to sound, dense kernels (Wilkins et al., 1993; Gaines et al., 1997). These quality characteristics cause low-density, shriveled kernels to have significantly poorer grain, milling, and baking quality. Since the degree of kernel shriveling is inversely proportional to kernel density (Gaines et al., 1997), it follows that kernel density is also inversely proportional to wheat quality.

#### STATISTICAL COMPARISON OF WHEAT SEGREGATED BY DENSITY TO NON-SEPARATED WHEAT

Samples collected in 2004 were analyzed to determine if significant ( $P = 0.10$ ) improvements in wheat quality and wheat quality consistency could be achieved through segregation of grain by density. Light grain at the 51 mm discharge position had significantly lower kernel density as compared to the other three fractions of segregated wheat and the non-separated sample (table 6). This low kernel density translated into a significantly lower test weight and consequently a lower wheat grade of U.S. No. 2. Significantly more dockage and shrunken and broken kernels were also contained in this sample. In contrast, the heavy grain at the 508 mm discharge position had significantly higher density and test weight as compared to all other density fractions and the non-separated sample. An exception to this was the fraction at the 356 mm discharge position. Grain at the 356 and 508 mm discharge positions had nearly identical kernel density. All measured or calculated quality attributes were not significantly different for these two fractions. Dockage and shrunken and broken kernels in these samples were negligible ( $\leq 0.1\%$ ) and significantly lower than the non-separated sample. Grain with low dockage and a minimal amount of shrunken and broken kernels may have added value since removal of unwanted wheat products reduces storage problems from mold and insects, lowers transportation costs, increases storage capacity, and improves handling efficiency. The low-density grain at the 51 mm position also had low break flour yield and significantly poorer protein, milling score, and MABS as compared to the two high-density fractions at the 356 and 508 mm positions. These poor quality characteristics translated into a significantly lower overall adjusted quality score as compared to



**Figure 4.** Effect of kernel density on soft white wheat grain, milling, end-use, and overall quality scores for grain collected near Helix, Oregon, in 2004 and 2005 and passed over a gravity table. Samples collected in 2004 were passed over a gravity table once and separated into four density fractions. Samples collected in 2005 were passed over a gravity table twice and separated into seven density fractions.

**Table 6.** Average kernel density and quality characteristics of soft white wheat exiting a gravity table at four discharge positions from samples collected near Helix, Oregon, in 2004.<sup>[a]</sup>

Discharge Position <sup>[b]</sup> (mm)	Weight Dist. <sup>[c]</sup> (%)	Density (kg m <sup>-3</sup> )	Wheat Grade (U.S.)	Dockage <sup>[d]</sup> (%)	Shrnk/ Brk <sup>[e]</sup> (%)	Test Weight (kg m <sup>-3</sup> )	Protein (%)	Break Flour (%)	Milling Score	MABS <sup>[f]</sup> (%)	Grain Quality Score	Milling Quality Score	MABS Score	Overall Quality Score Adj. <sup>[g]</sup>
Non-sep	--	1412 b	1 b	0.2 b	0.5 b	780 c	11.9 ab	48.0 b	84.3 ab	56.6 b	57.7 a	56.4 cb	58.8 a	57.0 b
51	24	1405 c	2 a	0.8 a	1.8 a	750 d	12.2 a	47.6 b	82.1 b	57.3 a	54.4 b	53.6 c	55.2 b	54.0 c
203	31	1413 b	1 b	0.2 bc	0.2 c	785 cb	11.7 ab	48.5 ab	84.8 a	56.2 b	58.9 a	57.6 ab	61.1 a	58.4 ab
356	24	1418 a	1 b	0.1 bc	0.1 c	791 ab	11.6 b	48.3 ab	84.8 a	56.3 b	59.8 a	57.3 abc	60.6 a	58.2 ab
508	21	1419 a	1 b	0.0 c	0.1 c	795 a	11.6 b	49.4 a	86.2 a	56.3 b	60.2 a	60.1a	60.8 a	60.2 a

[a] Within columns, means followed by the same letter are not different by Fisher's LSD test (P = 0.10).

[b] Position of center of collection chambers for grain discharged from gravity table measured from the left lower deck edge where small light seeds exit; Non-sep = non-separated.

[c] Distribution in terms of percentage of total weight of seeds discharged from a gravity table that accumulated in collection chambers.

[d] U.S. wheat grade dockage.

[e] U.S. wheat grade shrunken and broken kernels.

[f] Mixograph absorption

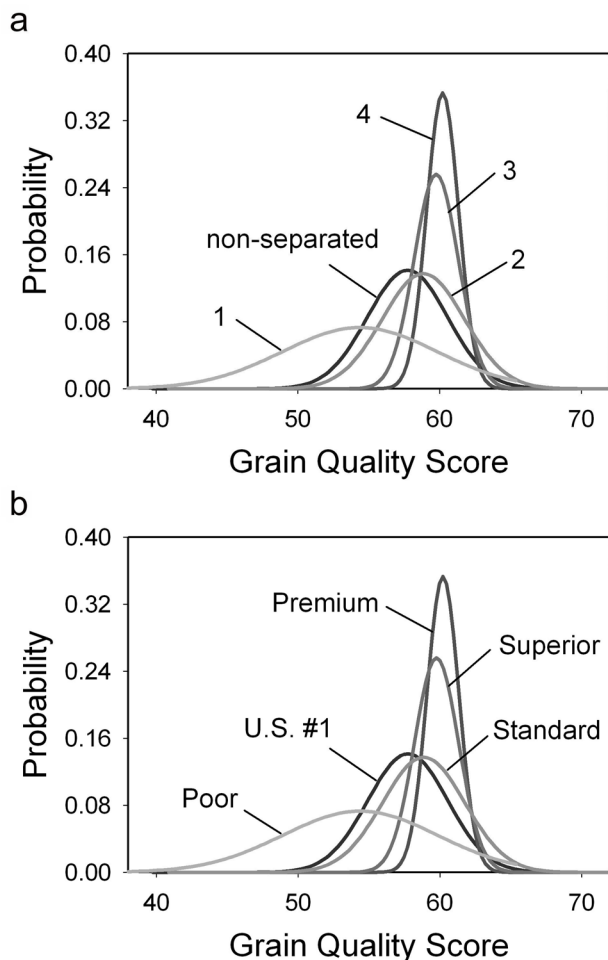
[g] Overall grain quality score adjusted to account for grain quality score, milling quality score, and mixograph absorption scores. Cookie diameter and end-use scores were not available.

the other three segregated fractions and the non-separated fraction. The only other result of consequence is that the high-density fraction at the 508 mm discharge position had a significantly higher adjusted overall quality score as compared to the non-separated fraction. Since the proportions of grain at the 51 and 508 mm discharge positions were 24% and 21% of the total grain respectively, these results show that substantial portions of significantly lower and higher quality wheat can be effectively segregated from lots of U.S. No. 1 and No. 2 wheat.

#### A NEW WHEAT CLASSIFICATION AND MARKETING SYSTEM

Because these results further indicated that density segregation is effective for separating wheat by quality, a new

wheat classification and marketing system was conceived that uses overall wheat quality as the basis for determining wheat grade. Such a system would be advantageous in the marketplace since overall quality takes into account not only the grain quality characteristics used in the current U.S. grading system but also milling and end-use wheat quality. An illustration to help explain the new classification system is presented in figure 5. Figure 5a shows normal distribution plots of the grain quality scores for the fractionated and non-separated 2004 samples. In this illustration, grain at the 51 mm discharge position had not only lower quality than the other fractions and the non-separated sample but also greater variability in quality as indicated by the flatter normal distri-



**Figure 5. Probability distribution for grain quality scores for grain collected near Helix, Oregon, in 2004 for non-separated grain and for grain passed over a gravity table and separated into four fractions. (a) Labels 1, 2, 3, and 4 indicate the four fractions of grain collected in chambers positioned with their centers at 51, 203, 356, and 508 mm, respectively, as measured from the left lower deck edge of the gravity table where small light seeds exit. (b) Labels indicate U.S. wheat grade for the non-segregated sample and proposed new classification grades for segregated grain.**

bution curve. High-density grain from the 508 mm discharge position had the highest grain quality score and the lowest variability (narrowest normal distribution curve). Grain from the 203 mm discharge position had roughly the same grain quality and variability as the non-separated sample. The quality-based classification system conceived is demonstrated figure 5b. Instead of U.S. No. 1 wheat (non-separated), one could market four grade classifications of grain, premium (508 mm discharge position), superior (356 mm discharge position), standard (203 mm discharge position), and poor (51 mm discharge position), based on wheat quality and consistency in wheat quality. Wheat price would depend on wheat grade classification and would be scaled as required to account for the added costs for segregation and extra handling. For such a system to be feasible, equipment for removing stones, metal, dirt, and other dense foreign materials may be required so that high-density fractions contained only high-quality grain. In addition, much further research is needed to define the relationship between overall wheat quality and kernel density to

ensure that grain sorted by density and placed into a particular grade classification would have consistent, predictable quality.

## CONCLUSION

This study showed that that grain, milling, end-use, and overall wheat quality were correlated with kernel density for one variety of soft white wheat produced using three different cropping systems in 2004 and 2005. Correlations between quality characteristics and kernel density ranged from poor to high ( $r^2 = 0.00$  to  $0.82$ ) for non-segregated samples but improved as the sample became more homogenous through segregation by density using a gravity table. For the 2005 samples passed over a gravity table twice, wheat quality characteristics of test weight, protein content, milling score, MABS, and cookie diameter were highly correlated with kernel density ( $r^2 = 0.94$  to  $0.95$ ). Break flour yield was also highly correlated with kernel density ( $r^2 = 0.89$ ). When the samples that had been collected in 2004 and passed over a gravity table once and the samples that had been collected in 2005 and passed over a gravity table twice were analyzed collectively, correlations between these quality characteristics and kernel density were similar, but slightly lower ( $r^2 = 0.88$  to  $0.94$ ). Quality scores calculated from these data and used to evaluate overall grain, milling, end-use, and overall wheat quality were also very highly correlated with kernel density ( $r^2 = 0.91$  to  $0.96$ ). These results indicate that kernel density is highly related to soft white wheat quality for homogenous samples of wheat segregated by a gravity table, but not necessarily related to wheat quality of non-separated samples. Segregation by density is effective because low-density, shriveled kernels have a lower ratio of endosperm to bran and germ and higher protein content as compared to sound dense kernels and therefore have poorer grain, milling, and baking quality characteristics. Additional research is needed to determine if the high correlations between wheat quality and kernel density found in this study exist for other cultivars of wheat and whether the relationships would be consistent across multiple cultivars of wheat. Analysis of data from more than two crop years and three cropping systems is also needed to confirm these findings.

When grain collected in 2004 was segregated into four density fractions, significant differences in wheat quality were obtained between the lowest density fraction, the highest density fraction, and the non-separated sample. Since the lowest and highest density fractions represented 24% and 21% of the total grain, respectively, these results showed that substantial portions of significantly lower and higher overall quality wheat can be effectively segregated from lots of U.S. No. 1 and No. 2 wheat. Because these results further indicated that density segregation is effective for separating wheat by quality, a new wheat classification was conceived that uses overall wheat quality as the basis for determining wheat grade. Since overall wheat quality takes into account not only the currently used grain quality measures of test weight and protein but also milling and end-use quality, such a system would be a competitive advantage since market grade would better reflect grain value. The new system would use four wheat grade classifications: poor, standard, superior, and premium. Prices would be set according to demand for each grade classification and the added costs for segregation. For such a system to be viable, much further research is needed

to define the relationship between overall wheat quality and kernel density to ensure that grain from multiple locations and years that had been sorted by density and placed into a particular grade classification would have consistent, predictable quality characteristics. In addition, although gravity table grain processing capacities are too slow to be commercially viable, recently developed and commercially available fluidized bed systems with high throughput and low cost could be used. The potential of these systems for adding value to soft white wheat through segregation by quality should be further explored.

## ACKNOWLEDGEMENTS

The authors would like to express their appreciation and gratitude to Clint and Paul Reeder for allowing wheat samples to be collected on their farm and for their cooperation in conducting these experiments. We also would like to thank Douglas A. Engle, Stewart B. Wuest, Donald E. Hulick, Andrew S. Ross, Jae B. Ohm, and Floyd E. Dowell for providing invaluable, expert technical assistance and information. Thanks are also extended Don Wysocki for his contribution of time and resources to this project and to the technical staff and many student workers at the USDA-ARS Columbia Plateau Conservation Research Center in Pendleton, Oregon, for their assistance with processing the samples. Finally, we would like to thank Jon Sperl and Pendleton Grain Growers for their cooperation and patience.

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